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The Economics of Roadside Bombs

A thesis submitted in partial fulfillment of the requirement
for the degree of Bachelors of Science in **Mathematics and Economics** from
The College of William and Mary

by

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Abstract

The U.S. military, despite spending over \$13 billion, appears powerless to stop the Iraqi insurgency's improvised explosive devices (IEDs), which cause most of the military's casualties and prevent victory by showing lawlessness and insecurity. However, this view ignores substitution effects we consider here. Using rational choice and expectations models, we find a backward-bending supply curve of attacks – insurgents increase the resources for IED attacks when IEDs are made less effective, but must therefore reduce non-IED attacks 2% for every 1% decrease in IED effectiveness. The success of the counter-IED effort has thus been significantly underestimated.

JEL Classification: C32; D74; H56.

Keywords: Iraq War; Instrumental Variables; Substitution Effects; Backward-Bending Supply Curve; Insurgency; Terrorism.

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I. Introduction

This paper presents an economic analysis of one major component of the war in Iraq – the battle against improvised explosive devices (IEDs). Economic analysis of warfare has been an active area of research for decades (e.g. Schelling (1960)), and has been applied to insurgency (e.g. Leites and Wolf (1970)), terrorism (e.g. Enders and Sandler (2006), Enders, Sandler and Cauley (1991), Jaeger and Paserman (2006), Rosendorff and Sandler (2004), Sandler and Enders (2002)), and specifically the war in Iraq (e.g. Davis, Murphy and Topel (2006)). We present empirical results of maximizing behavior in the Iraqi insurgency, its relation to microeconomic theory, and implications for the fight against IEDs.

Since the invasion of Iraq in March 2003, the insurgency that has arisen to fight the Coalition has killed and wounded thousands of U.S. soldiers.¹ Of the deaths, most have been killed by improvised explosive devices (IEDs). IEDs, also known as roadside bombs, are a “device placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic, or incendiary chemicals and designed to destroy, incapacitate, harass, or distract.”²

The United States military has spent a great deal of its resources on combating IEDs. The Joint IED Defeat Organization (JIEDDO), an agency unifying the efforts of all the military services to defeat these bombs, has received over \$13 billion in funding since 2004. JIEDDO and the overall counter-IED effort have been criticized for their apparent inability to stop or even reduce the number of IED attacks. A Boston Globe news article referred to JIEDDO as “the controversial office that has spent billions of dollars but failed to curb the biggest killer of American troops,” and noted that “lawmakers have become increasingly frustrated by its secrecy and apparent lack of progress in stemming the roadside bomb threat.”³ However, no analysis has yet estimated the impact of IED countermeasures on other types of attacks, which are causally linked due to resource constraints. Because

¹The Coalition is made up of 33 nations, but the United States has contributed the overwhelming majority of the troops and funding from the initial occupation to the present day.

²Definition from the Joint IED Defeat Organization.

³Bender, Bryan, “War strategy critic to review IED office,” Boston Globe, April 16, 2007.

insurgents do not have infinite resources, if a countermeasure increases the resources required for an effective attack, *ceteris paribus*, it decreases the resources available for non-IED attacks.

In this analysis, we consider the income and substitution effects from a decrease in IED effectiveness. To identify the results of a shift in the cost of conducting IED attacks, we use the variation in the percentage of IED attacks that are effective, which changes the resources necessary to conduct an effective IED attack. Considering the graph presented in Figure 1, IED attacks appear to *increase* with a decrease in the percentage of IED attacks that are effective – a situation analogous to the backward-bending supply curve of labor, where hours worked can increase with a decrease in wages. If the insurgents are resource-constrained, the increase in the number of IED attacks attempted comes at the cost of other types of attacks.

If IED attacks decrease with a decrease in IED effectiveness, evaluations of the counter-IED effort that do not consider its impact on non-IED attacks have overstated the counter-IED effort's success (because they do not consider the additional non-IED attacks that result). If IED attacks increase with an increase in IED effectiveness, however, evaluations of the counter-IED effort that do not consider its impact on non-IED attacks have understated the counter-IED effort's success (because they do not consider the decrease in non-IED attacks that results).

[Figure 1 about here]

When countermeasures reduce the returns to an attack (and increase the resources required for success), they are likely to change insurgent behavior. Benmelech and Berrebi (2007) found that Palestinian organizations conducting suicide bombings engage in optimizing behavior – bombers with higher levels of human capital are assigned to higher-value targets. Enders and Sandler (1993), studying transnational terrorism, found that metal detectors in airports and the hardening of buildings decreased skyjackings and attacks against embassies but increased hostage-taking and assassinations – close substitutes for transnational terrorists. These empirical results suggest that various kinds of transnational

terrorism, on a single-good basis, will decrease with a decrease in effectiveness.

We demonstrate below that a Coalition countermeasure, which we identify through its effect on insurgent trigger use, which reduces the probability that an IED attack will be effective has no statistically significant impact on the number of observed IED attacks the insurgents conduct. However, these innovations do reduce the number of non-IED attacks. We also show that a decrease in the resources of the insurgency causes the insurgents to do proportionally more IED attacks. Because IED attacks, unlike transnational terrorist attacks, do not decrease with a decrease in effectiveness, the effects of the countermeasures deployed by the U.S. military have been significantly understated.

II. Theory, Data, and Methodology

We develop here a model of the levels of IED attacks and non-IED attacks selected by the insurgents.⁴ Adapting the choice-theoretic model of Landes (1978):

$$\mathbb{E}[U_I] = p_I U_{I,S} + (1 - p_I) U_{I,F} \quad (1)$$

where $\mathbb{E}[U_I]$ is the expected utility increase if the insurgents attempt an IED attack, p_I is the probability that an IED attack will be effective, $U_{I,S}$ is the utility from an effective IED attack, and $U_{I,F}$ is the utility from an unsuccessful (ineffective or found and cleared) IED attack, with $U_{I,S} > U_{I,F}$. Insurgents conduct a marginal IED attack if $\mathbb{E}[U_I]$ exceeds the cost of an IED attack, which we denote below as a , and a marginal non-IED attack if $\mathbb{E}[U_N] > b$ for the cost of a non-IED attack b .⁵

For a fixed number of attempted IED or non-IED attacks I, N , the number of effective attacks is distributed according to $I_S \sim \text{Binomial}(I, p_I), N_S \sim \text{Binomial}(N, p_N)$, with

⁴The problem is analogous to insurgent groups as consumers of IED and non-IED attacks, or insurgent groups as producers of damage with IED and non-IED attacks as inputs. We do not attempt to distinguish between the different cases, because both can generate what we term here the income and substitution effects, and the implications of these effects are interpreted the same way regardless of whether the insurgency is considered to be consumers or producers.

⁵Note that utility can include non-kinetic effects such as public relations problems for the Coalition – such effects are one reason why $U_{I,F}$ and $U_{N,F}$ may be positive.

expected values $\mathbb{E}[I_S] = p_I I$, $\mathbb{E}[N_S] = p_N N$. Using this formulation to expand the choice-theoretic model to the aggregate number of IED attacks and non-IED attacks attempted, we can therefore presume that insurgents maximize the damage they inflict on the Coalition subject to resource constraints:

$$\max \quad \mathbb{E}[U(I, N)] \quad (2)$$

$$\text{s.t.} \quad aI + bN \leq R \quad (3)$$

where U is a utility function that increases monotonically with the number of IED attacks I and the number of non-IED attacks N , R is the resources available to the insurgents, and a and b represent resources expended for an attempted IED attack or an attempted non-IED attack. With limited assumptions on the behavior of this system,⁶ it is analogous to a consumer maximizing utility by selecting a bundle of goods or a firm maximizing output.

Relabel the expected resources expended per effective IED attack as $f = \frac{a}{p_I}$ and per effective non-IED attack as $g = \frac{b}{p_N}$, assuming a and b constant – this allows the probabilities of effectiveness for IED and non-IED attacks to enter the equations directly. With this change, the solution to the maximization problem can be written as

$$\bar{I} = \bar{I}(f, g, R) \quad (4)$$

$$\bar{N} = \bar{N}(f, g, R) \quad (5)$$

$$\bar{\lambda} = \bar{\lambda}(f, g, R) \quad (6)$$

with λ as the Lagrange multiplier, interpreted as the marginal insurgent utility resulting

⁶Diminishing marginal returns to IED and non-IED attacks, and little or no complementary effects of damage across IED and non-IED attacks.

from additional resources. The comparative-static derivatives are⁷

$$\partial \bar{I} / \partial R = (gD_{IN} - fD_{NN}) / \det(\bar{H}) \quad (7)$$

$$\partial \bar{N} / \partial R = (fD_{IN} - gD_{II}) / \det(\bar{H}) \quad (8)$$

and

$$\partial \bar{I} / \partial f = -g^2 \bar{\lambda} / \det(\bar{H}) - \bar{I} \cdot (\partial \bar{I} / \partial R) \quad (9)$$

$$\partial \bar{N} / \partial f = fg \bar{\lambda} / \det(\bar{H}) - \bar{I} \cdot (\partial \bar{N} / \partial R) \quad (10)$$

We do not directly observe the cost of an IED or non-IED attack, denoted above as a and b . However, changes in the benefits of an attempt from changes in effectiveness are observable. We therefore can investigate the effect of an exogenous decrease in the benefit of conducting an IED attack – an exogenous decrease in IED effectiveness p_I . According to the choice-theoretic model outlined above, a decrease in the benefits has exactly the same effect on the number of IED attacks conducted as some increase in the costs would have. We can therefore treat a decrease in the benefits of attempting IED attacks exactly as we would treat an increase in the cost.⁸

In the above formulations, the quantities $\bar{I} \cdot (\partial \bar{I} / \partial R)$ and $\bar{I} \cdot (\partial \bar{N} / \partial R)$ are the income effect from changes in price, and $-g^2 \bar{\lambda} / \det(\bar{H})$ and $fg \bar{\lambda} / \det(\bar{H})$ are the substitution effect. Note that the number of IED attacks could increase or decrease in response to a change in f . An increase could be the result of behavior analogous to the backward-bending supply curve of labor – if the insurgents are “targeting” a certain level of attacks (which can result from marginal returns to IED attacks decreasing with the level of IED attacks), a decrease in IED effectiveness will cause an increase in the number of IED attacks, and a decrease in the number of non-IED attacks. In order to test this hypothesis, we estimate these effects

⁷We use subscripts here to indicate a partial derivative.

⁸There is no data available on the number of effective non-IED attacks, so the model is incomplete if the goods considered are effective attacks rather than attempted attacks.

through Equations 4 and 5 using publicly available data from U.S. government sources. A detailed description of the data collection is presented in the Data Appendix. A time-series plot of the total number of IED attacks and the number of effective IED attacks is presented in Figure 2.

[Figure 2 about here]

In order to make these reduced-form equations operational, we use the effectiveness of IED attacks (contemporaneously and with one lag) as a measure of changes in the price (the resources required) to carry out IED attacks. There has been no systematic effort on the scale of JIEDDO to reduce the effectiveness of non-IED attacks, so we therefore assume that this change can be appropriately modeled by a linear trend.⁹ As a proxy for the resource constraint, we use the numbers of IED and non-IED attacks in the previous period.¹⁰ To allow for differing autoregressive effects, we split these into two variables in each equation.¹¹

The effectiveness of IED and non-IED attacks may be endogenous – in particular, they may vary simultaneously with the number of IED and non-IED attacks attempted. Furthermore, there may exist correlations between the effectiveness of IED attacks and non-IED attacks. We therefore require an instrument that is exogenous.

IEDs are triggered with a variety of systems – by radio control, command wire, pressure plate (similar to a landmine), passive infrared sensors, or cell phones. Contemporaneously, the percentage of IEDs that are not triggered by radio control are exogenous once past IED effectiveness (the factor that determines what types of attacks to attempt this period) is controlled for. The percentage of non-radio-control triggers used is determined by Coalition jammer use, which is not a function of contemporaneous insurgent activity.

⁹We tested quadratic trends, but did not reject the null hypothesis of no significance.

¹⁰Although this proxy may introduce measurement error, the instruments for the effectiveness of IED attacks are likely to be exogenous with respect to the resource constraint, and therefore allow identification of variation due to changes in IED effectiveness rather than in the resource constraint. The results may therefore be less susceptible to the adverse effects of measurement error due to the use of these instrumental variables.

¹¹As noted in the empirical results, we also tested the use of Iraqi prison population as a proxy for total insurgent resources, and did not reject the null hypothesis of no significant information.

Jammer use is, perhaps paradoxically, exogenous with respect to IED and non-IED attacks. Coalition forces use all the IED countermeasures available to them since the marginal cost is extremely low, and the available IED countermeasures are the result of spending decisions made in previous periods. The marginal cost of additional use of IED jamming systems once they have been fielded is only the electrical power to operate them. Although it is possible that these systems could be deployed in anticipation of higher insurgent effectiveness in the future (making jammer use endogenous), JIEDDO has been criticized for being too slow to react to insurgent innovations. A paper written by three field-grade military officers, Ellis, Rodgers and Cochran (2007), describes JIEDDO as being mired in red tape and unable to effectively respond to new developments in insurgent IED technology.¹² Similar issues are raised in Adamson (2007) – authored by the former operations officer of JIEDDO. While JIEDDO has been able to identify some trends in the counter-IED fight, it is virtually impossible to predict insurgent activity, and the long lag in acquisition decisions to deployment of systems prevents these systems from being endogenous responses to contemporaneous insurgent activity. We therefore assume that jammer use is exogenous.

We also assume that insurgents cannot detect changes in countermeasures activity, formulate a response, and execute that response in the same period. Therefore, the decisions about what trigger use to attempt are not a function of contemporaneous countermeasures use. However, the triggers actually observed are a function of countermeasures use, which is exogenous. The use of jammers prevents radio frequency emissions that could trigger an IED. When a jammer is successful, those attempted attacks are not observed because the IED does not detonate. This effect necessarily reduces the observed radio control detonated IEDs and causes a higher proportion of non-radio control triggers to be in the population of observed IEDs. Therefore, use of jammers results in a contemporaneous reduction in the percentage of IEDs observed using radio control triggers. We can use this association between non-radio control trigger use and IED effectiveness to represent the decrease in IED effectiveness due to jammer use.

¹²This paper is at http://www.jfsc.ndu.edu/current_students/documents_policies/documents/jca_cca_awsp/.

In order to control for innovations in insurgent technology (which may have both direct and spillover effects), we use passive infrared trigger use as a proxy. These triggers are generally used only with explosively formed penetrator IEDs, which, although they are highly lethal, require a high degree of technical sophistication to construct and emplace.

We therefore estimate a contemporaneous instrumental variable (IV) model:

$$\widehat{\Delta I}_t = \alpha_0 + \alpha_1 \widehat{\Delta E}_t + \alpha_2 \Delta E_{t-1} + \alpha_3 \Delta I_{t-1} + \alpha_4 \Delta N_{t-1} + \epsilon_1 \quad (11)$$

$$\widehat{\Delta N}_t = \beta_0 + \beta_1 \widehat{\Delta E}_t + \beta_2 \Delta E_{t-1} + \beta_3 \Delta I_{t-1} + \beta_4 \Delta N_{t-1} + \epsilon_2 \quad (12)$$

$$\widehat{\Delta E}_t = \gamma_0 + \gamma_1 \Delta G_{CW,t} + \gamma_2 \Delta G_{PP,t} + \gamma_3 \Delta G_{IR,t} + \gamma_4 \Delta G_{CP,t} + \epsilon_3 \quad (13)$$

where I is the number of IED incidents, N is the number of non-IED attacks, E is the average effectiveness of an IED attack, G_{CW} is observed command wire triggers, G_{PP} is observed pressure plate triggers, G_{IR} is observed passive infrared triggers, and G_{CP} is observed cell phone triggers. $\widehat{\Delta E}_t$ and ΔE_{t-1} are proxies for f , while ΔI_{t-1} and ΔN_{t-1} are proxies for R in Equations 4 and 5. The $\epsilon_1, \epsilon_2, \epsilon_3$ are the equation error terms, which are assumed to be serially uncorrelated. However, as discussed below, we allow correlations to exist across the different equations in the same time period, and account for this using a system estimation procedure that increases efficiency.

As a check on the robustness of the specification to problems such as endogeneity of the instruments, we also specify a simple dynamic rational expectations model using orthogonality conditions. Suppose that the insurgents use an optimal forecast function h to predict the effectiveness of IED attacks, and choose their levels of IED and non-IED attacks accordingly. Then the difference between the insurgents' forecast and the realization of IED effectiveness at time t is uncorrelated with any variables observed at time $t - 1$. We can therefore generate orthogonality conditions for an alternative estimate of Equation 13,

$$\mathbb{E}[(\Delta E_t - \Delta h(\mathbf{X}_{t-1})) \otimes \mathbf{X}_{t-1}] = \mathbf{0}$$

where \otimes is the Kronecker product and \mathbf{X}_{t-1} is a vector of information observed at time $t - 1$. For \mathbf{X}_{t-1} , we use lags of the instruments (trigger use, past effectiveness) from the contemporaneous IV specification, and for h , we use a linear forecast. This specification corresponds to the instrumental variable specification above, but with lagged rather than contemporaneous instruments.

The equation error terms are almost certainly correlated: the whole point of this analysis is that an insurgent group choosing to conduct one more IED attack necessarily cannot conduct as many non-IED attacks, and vice versa. We therefore use system estimation methods to increase efficiency. We conducted estimation using both the three-stage least squares (3SLS) and generalized method of moments (GMM) estimators. The two estimates produced very similar results for parameter estimates. GMM standard errors may be biased in small samples; we therefore present below the 3SLS estimates for the two models.

III. Empirical Results

We find that all of the series appear to be unit root processes.¹³ Therefore, we estimate the relationships in first differences.¹⁴ All variables except the instruments (which take on zero values) are expressed in logarithms.

The specification is robust to the removal of some variables (for example, the effectiveness variables in the IED equation), but the estimates vary wildly when the constants are excluded. As the constants are one of the proxies used for total insurgent resources (thereby representing a linear trend in levels), this effect is likely due to omitted variable bias. As a robustness check on the quality of the proxies for total insurgent strength (the linear trends and autoregressive terms), we also tested the specification with the inclusion of a trend in the differences specification (a quadratic trend in levels) and variables for the size of the Iraqi prison population over time.¹⁵ These variables were jointly insignificant, so they were

¹³Testing was done with the augmented Dickey-Fuller test and the efficient unit root test outlined in Elliot, Rothenberg and Stock (1996). Both showed a strong probability of the presence of a unit root.

¹⁴There is little evidence that any cointegrating relationships exist in the data.

¹⁵These estimates can be found in the Brookings Institution's Iraq Index at

omitted in the specification below to increase efficiency.¹⁶

Estimation of the contemporaneous IV model produces:

$$\widehat{\Delta I_t} = 0.054^{**} + 0.031 \widehat{\Delta E_t} + 0.076 \Delta E_{t-1} - 0.310 \Delta I_{t-1} - 0.069 \Delta N_{t-1} \quad (14)$$

$$(T = 34 \quad \bar{R}^2 = 0.115 \quad \hat{\sigma} = 0.115)$$

$$\widehat{\Delta N_t} = 0.116^* + 1.281^* \widehat{\Delta E_t} + 0.757^* \Delta E_{t-1} - 1.001^* \Delta I_{t-1} - 0.170 \Delta N_{t-1} \quad (15)$$

$$(T = 34 \quad \bar{R}^2 = 0.240 \quad \hat{\sigma} = 0.334)$$

(standard errors in parentheses)

** significant at the 5% confidence level

* significant at the 10% confidence level

Estimation of the dynamic rational expectations model produces:

$$\widehat{\Delta I_t} = 0.059^{**} + 0.046 \widehat{\Delta E_t} + 0.021 \Delta E_{t-1} - 0.370^* \Delta I_{t-1} - 0.052 \Delta N_{t-1} \quad (16)$$

$$(T = 33 \quad \bar{R}^2 = 0.152 \quad \hat{\sigma} = 0.114)$$

$$\widehat{\Delta N_t} = 0.176^{**} + 2.709^* \widehat{\Delta E_t} + 0.633 \Delta E_{t-1} - 1.209^* \Delta I_{t-1} - 0.079 \Delta N_{t-1} \quad (17)$$

$$(T = 33 \quad \bar{R}^2 = -0.034 \quad \hat{\sigma} = 0.395)$$

(standard errors in parentheses)

** significant at the 5% confidence level

* significant at the 10% confidence level

Tests of the residuals for normality and the absence of serial correlation, as well as tests for the validity of the overidentifying restrictions, suggest that the models are well-specified.

<http://www.brookings.edu/saban/iraq-index.aspx>. We used linear interpolation for the missing data points.

¹⁶Specifying the model using only the differenced Iraqi prison population variable instead of the constants and autoregressive effects results in qualitatively similar coefficient estimates, though without statistical significance. We attribute these results to omitted variable bias from excluding those variables. Specifying the model with all these variables included also results in qualitatively similar coefficient estimates, but with no variables individually significant. We attribute this result to decreased efficiency from an overparameterized model with moderate collinearity in the proxies.

We present the results of the Anderson-Darling test for normality of the residuations in Figures 3, 4, 5, and 6.

[Figures 3, 4, 5, and 6 about here]

We present in Table 1 the results of tests for the significance of $\alpha_1 + \alpha_2$ and $\beta_1 + \beta_2$, representing our hypothesized effects over two months. We accept the null hypothesis of no effect of IED effectiveness on IED attacks, but a positive effect of IED effectiveness on non-IED attacks.

[Table 1 about here]

The two models produce congruent results, as evidenced by Figure 7. The ellipses present the cross-equation confidence ellipses, while the gray area represents the single-equation significance of the IED and non-IED coefficients in the contemporaneous IV model, and the dashed gray lines represent the single-equation significance of the IED and non-IED coefficients in the dynamic rational expectations model. Each model's point estimate is within the other's 95% confidence region. Both models find a magnitude- and statistically-significant effect of IED effectiveness on non-IED attacks, but not on IED attacks.

[Figure 7 about here]

IV. Discussion

The key question for this analysis is the interpretation of the sums $\widehat{\alpha}_1 + \widehat{\alpha}_2$ and $\widehat{\beta}_1 + \widehat{\beta}_2$. These sums represent the effect, over two months, of a change in IED effectiveness on IED and non-IED attacks, respectively.¹⁷ Results from this model suggest that a major way IED countermeasures are effective is in reducing non-IED attacks. The model finds that a 1% decrease in IED effectiveness decreases non-IED attacks by 2%-3% (the sum of the estimated coefficients $\widehat{\beta}_1$ and $\widehat{\beta}_2$). In response to a Coalition negative effectiveness

¹⁷We do not discount an attack prevented by reduced effectiveness next month more than an attack prevented by reduced effectiveness this month, which is why the sums $\widehat{\alpha}_1 + \widehat{\alpha}_2$ and $\widehat{\beta}_1 + \widehat{\beta}_2$ are left unweighted relative to each other.

innovation, insurgents increase the number of IED attacks conducted (and because the proportion of unobserved IED attacks is higher, the number of observed IED attacks remains approximately the same – manifested by the coefficients in Equations 14 and 16 being insignificant). Therefore, IED countermeasures will appear to have no deterring effect against IED attacks, and in fact, both the number of effective attacks and the number of casualties due to IEDs will appear stable. However, analysis of these first-order effects ignore the additional resources required to inflict casualties.

Because additional resources are now required to inflict the same number of casualties, fewer resources are available, *ceteris paribus*, to carry out non-IED attacks. As shown below, this effect is the primary mechanism by which IED countermeasures are effective, for the response of non-IED attacks to a decrease in IED effectiveness is large: 2.04 in the contemporaneous IV model and 3.34 in the dynamic rational expectations model ($\hat{\beta}_1 + \hat{\beta}_2$).

We use the constant term as a proxy for total insurgent resources. We find that, *ceteris paribus* the ability of insurgents to conduct IED attacks increases by 5%-6% per month, while the ability of insurgents to conduct non-IED attacks increases by 11%-17% per month. These increases may be due to increases in the amount of resources available to the insurgents, or technological progress that allows the insurgents greater efficiency in conducting these attacks.

In order to estimate the total effect IED countermeasures have had on non-IED attacks, we estimate the effect Coalition countermeasures have had, as measured through the instruments. An OLS regression of IED effectiveness on the instruments returns the coefficients determining ΔE_t (we present here the contemporaneous IV model's estimates). Using these coefficients, it is possible to recover an estimate of the total effect IED countermeasures, as measured through decreases in IED effectiveness, have had on non-IED attacks. With the contemporaneous IV estimate of a response of 2.04, we find that these countermeasures have prevented 1,710 non-IED attacks.

The first-order effect that these countermeasures have had (turning what would have been effective IED attacks into ineffective IED attacks) is estimated, using the above OLS

regression of Equation 13, to be 1,504 IED attacks. These estimates show that the number of non-IED attacks prevented by IED countermeasures actually exceeds the number of IED attacks rendered ineffective by them. Furthermore, the countermeasures have no significant effect in reducing the number of IED attacks the insurgents attempt – they only reduce non-IED attacks in the data observed.

While these differences may seem small relative to the overall amount of money spent in the counter-IED fight, these estimates represent lower bounds on the effectiveness of IED countermeasures. We consider only jammers, a subset of the total counter-IED effort. There may be changes in Coalition techniques, tactics, and procedures, or innovations that reduce the expected number of casualties inflicted when casualties are taken. The actual impact of the overall counter-IED effort on non-IED attacks is likely to be considerably higher than the estimates presented here.

V. Conclusion

We have estimated the responses of the levels of IED and non-IED attacks selected by insurgents in Iraq to increased Coalition countermeasures, using contemporaneous and lagged IED trigger use as instruments for IED effectiveness. We find that IED countermeasures have no significant impact in reducing the number of IED attacks conducted, but they do reduce the number of non-IED attacks the insurgency conducts. We find that a one percent decrease in IED effectiveness due to countermeasures decreases non-IED attacks by at least two percent, and that IED countermeasures have thus prevented the insurgency from carrying out at least 1,710 non-IED attacks it otherwise would have. The number of non-IED attacks prevented exceeds the number of IED attacks rendered ineffective by the countermeasures, suggesting that the effectiveness of the \$13 billion spent on IED countermeasures has been significantly understated.

Data Appendix

The data used are time series for the number of effective (defined as attacks that kill or wound at least one Coalition soldier) and ineffective IED attacks per month, the number of IEDs found and cleared, the total number of IED attacks per month, the number of total attacks per month (all methods), and the monthly percentages used of six IED triggers. The total number of IED attacks is defined to be the sum of ineffective and effective IED attacks plus the number of IEDs found and cleared. The number of non-IED attacks is the difference of the number of total attacks and the total number of IED attacks. Effectiveness is defined as the number of effective IED attacks divided by the number of total IED incidents (including IEDs found and cleared).¹⁸ The sample is June 2004-April 2007.

The data on the total number of attacks per month are from *Rebuilding Iraq: Integrated Strategic Plan Needed to Help Restore Iraq's Oil and Electricity Sectors* (2007). The data on the number of effective, ineffective, and found/cleared IED incidents per month, as well as the time series for the six triggers observed, come from a Joint IED-Defeat Organization (JIEDDO) PowerPoint briefing.¹⁹ In both cases, the data is collected from graphs in the documents.²⁰ Although the scale bars on the graphs have been removed in the PowerPoint presentation and in the GAO report, the numbers can be inferred from reports which have stated several monthly numbers of IED attacks. Furthermore, the measurement error inherent in this process is considerably smaller than even the differences in the counts of IED attacks kept by different U.S. Department of Defense agencies. In this way, it is possible to create a highly accurate representation of trends in the IED fight from entirely unclassified, public data.²¹

¹⁸JIEDDO defines an effective attack as one that produces casualties.

¹⁹The briefing can be found on the Department of Defense website <http://www.acq.osd.mil/ic/>.

²⁰Although the data underlying these graphs is classified, the data on the graphs can be interpolated with better than 95% precision based on the size of the pixels – therefore, measurement error above and beyond any errors that may exist in the underlying data is very limited. Interpolation was conducted by counting the pixels on the graphs and generating an attacks per pixel value from several monthly values publicly announced by the Coalition.

²¹As a check on the quality of the data, the interpolated data agree closely with data presented in Atkinson (2007). Atkinson also identifies the six triggers: low-power radio control, high-power radio control, passive infrared, command wire, pressure plate, and cell phone.

Abbreviations

IED: Improvised Explosive Device

IV: Instrumental Variables

JIEDDO: Joint Improvised Explosive Device Defeat Organization

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Figure 1: IED Attacks and IED Effectiveness.

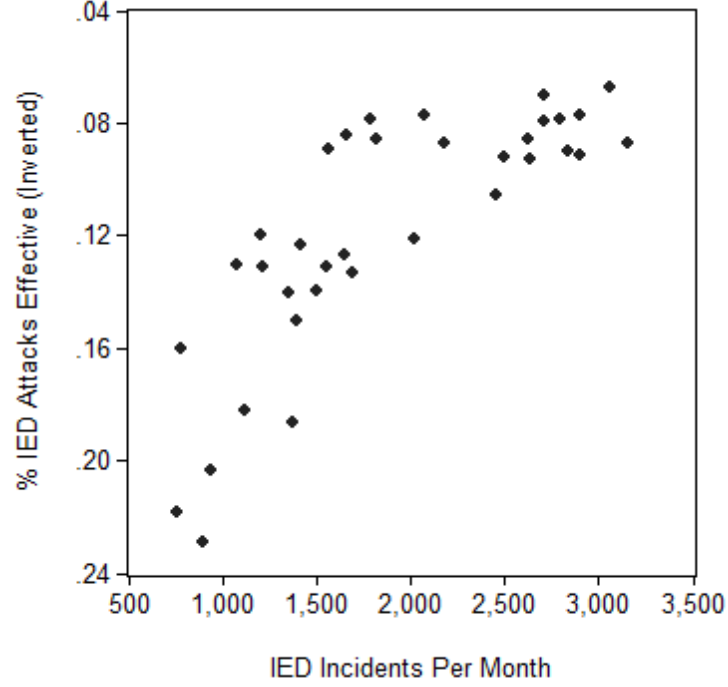


Table 1: Wald Coefficient Tests for Significance of IED Effectiveness.

Model	H_0	$\chi^2(1)$	p -value
Contemporaneous IV	$\alpha_1 + \alpha_2 = 0$	0.1051	0.7458
Contemporaneous IV	$\beta_1 + \beta_2 = 0$	4.5116	0.0337
Dynamic Rational Expectations	$\alpha_1 + \alpha_2 = 0$	0.0238	0.8775
Dynamic Rational Expectations	$\beta_1 + \beta_2 = 0$	4.9012	0.0268

Figure 2: Total IED Incidents and Effective IED Incidents.

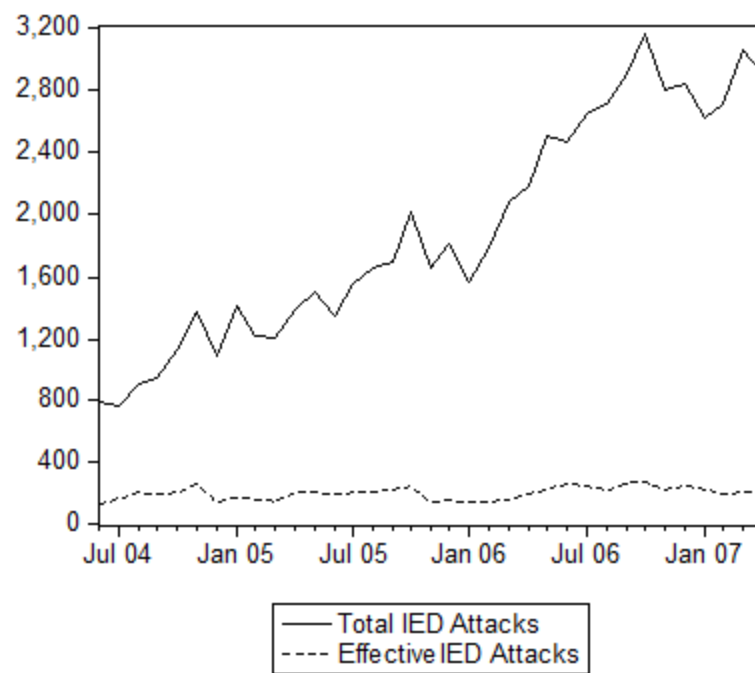


Figure 3: Anderson-Darling Test for Normality, Contemporaneous IV IED Equation.

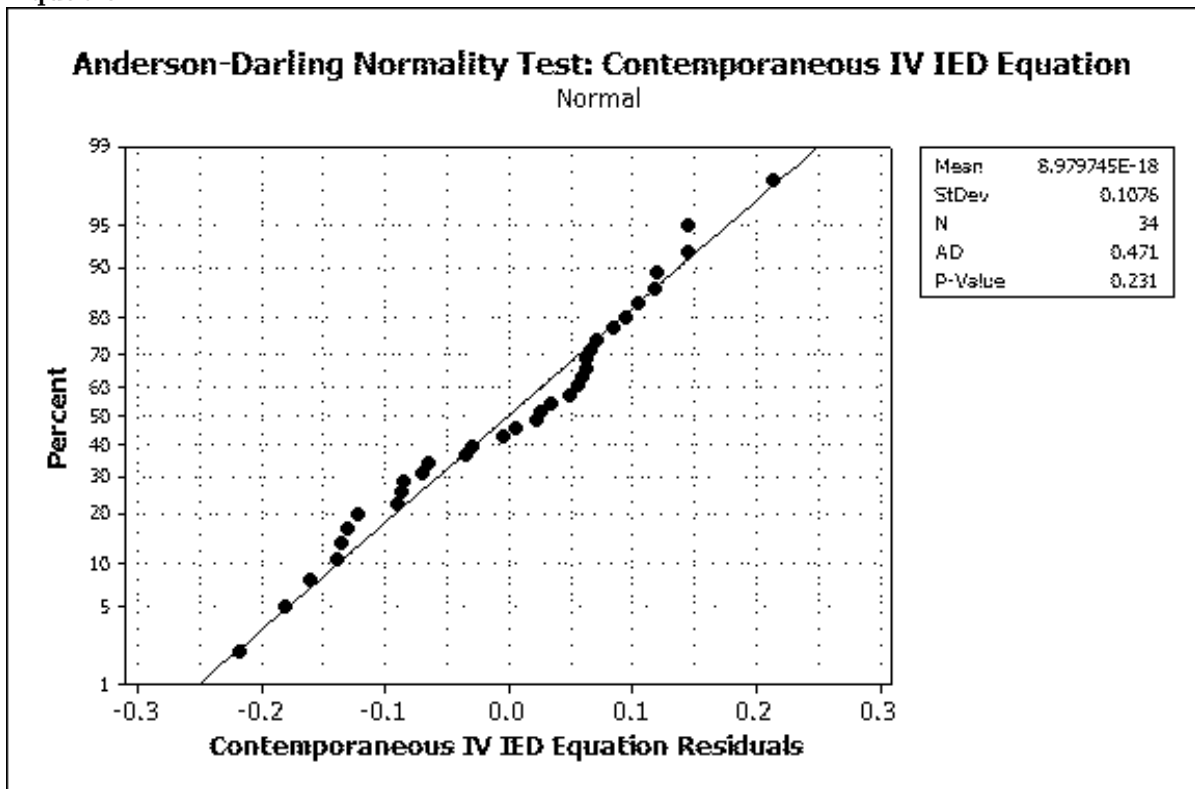


Figure 4: Anderson-Darling Test for Normality, Contemporaneous IV Non-IED Equation.

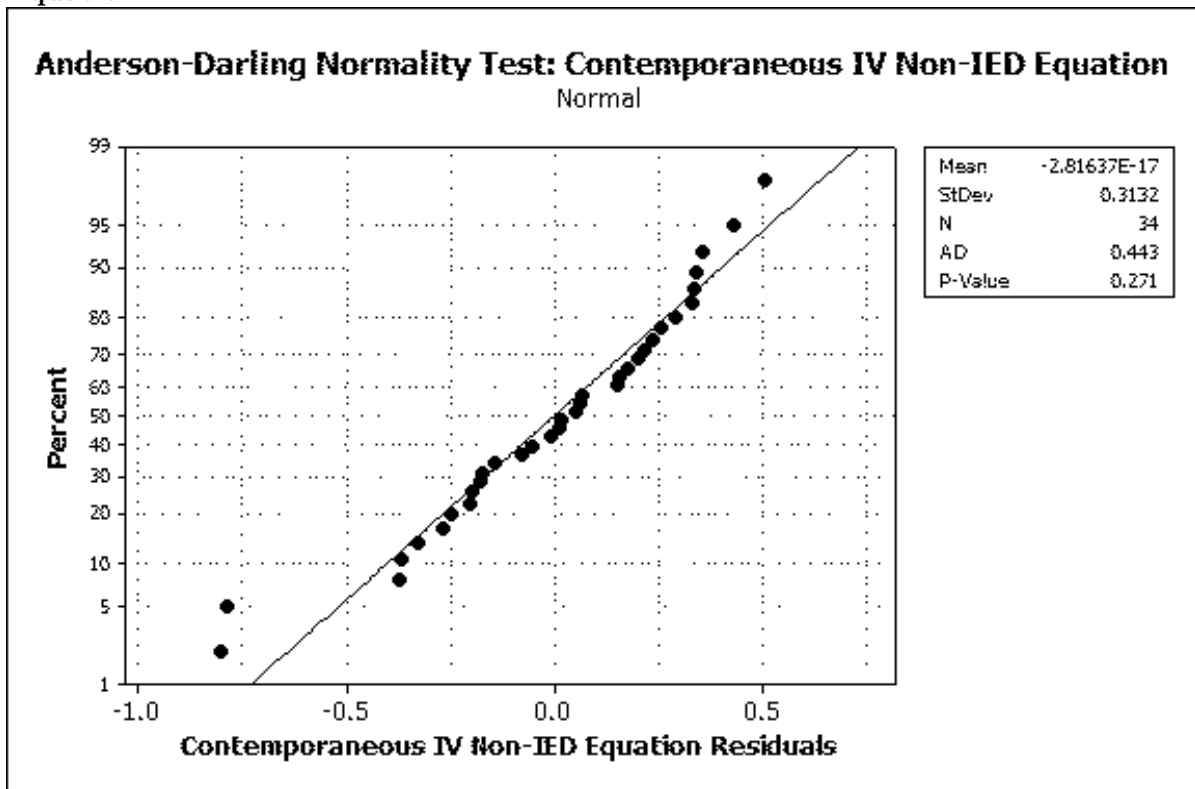


Figure 5: Anderson-Darling Test for Normality, Dynamic Rational Expectations IED Equation.

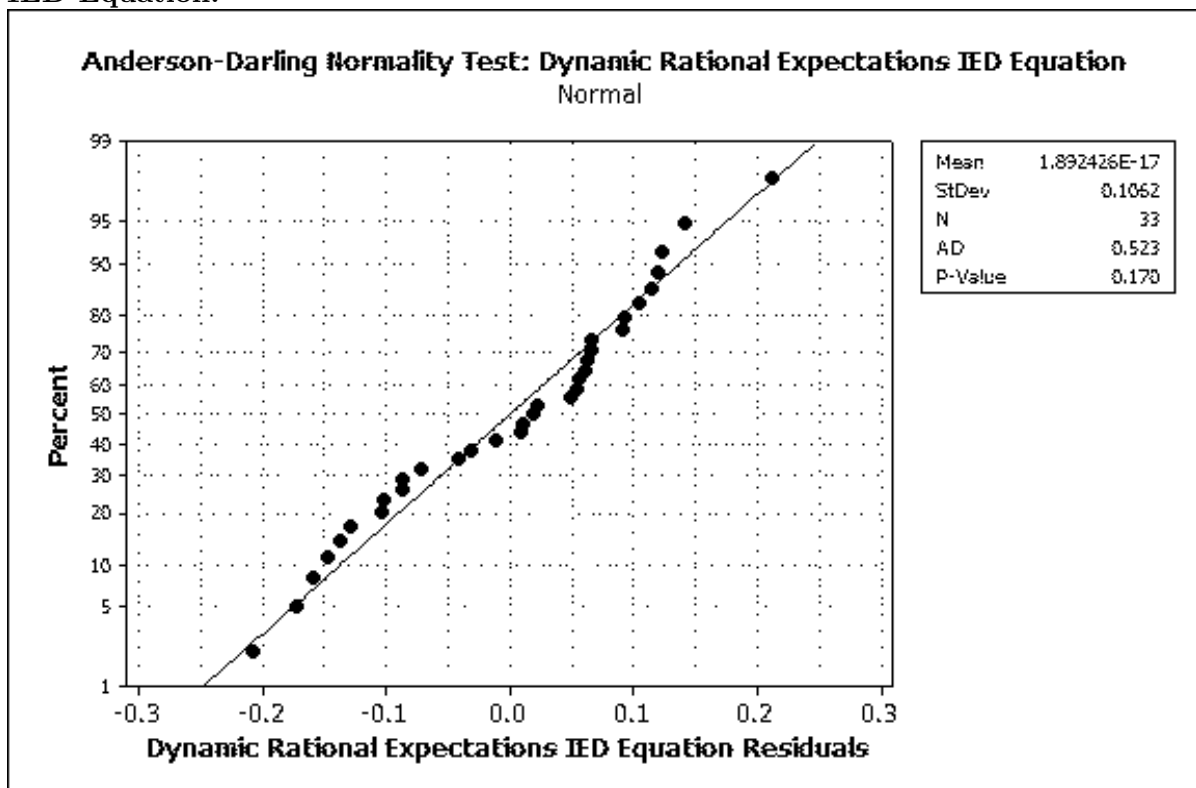


Figure 6: Anderson-Darling Test for Normality, Dynamic Rational Expectations Non-IED Equation.

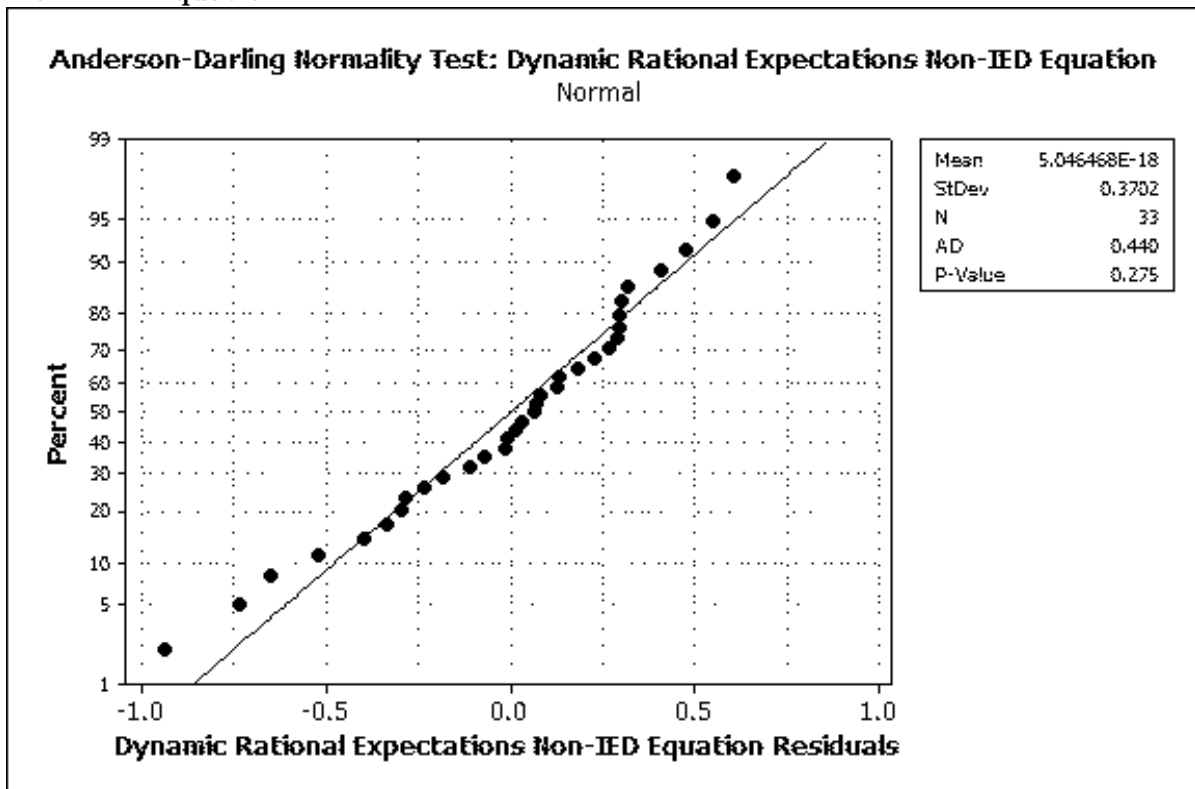


Figure 7: 95% Confidence Regions, Cross- and Single-Equation Estimates.

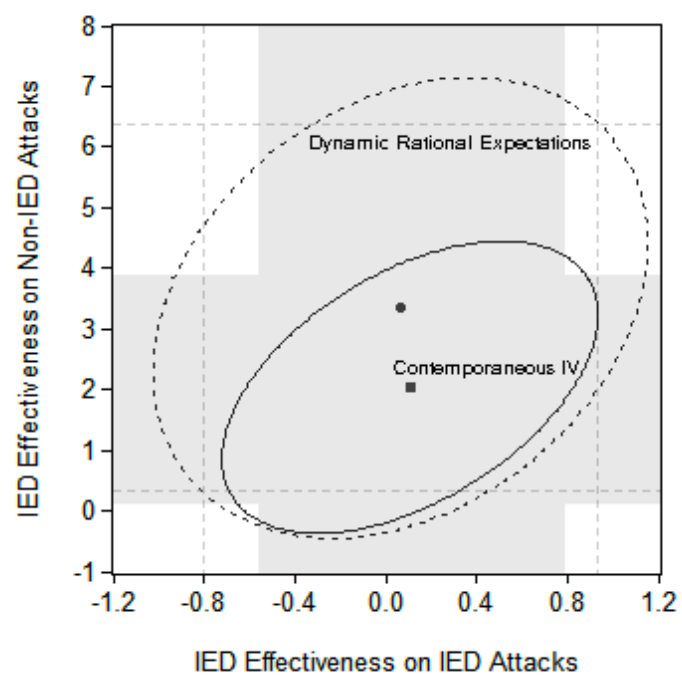


Table 2: Interpolated Data.

Month	LPRC	HPRC	PI	CW	PP	CP	IED-FC	IED-I	IED-E	IED	NIED
6/04	0.674	0.295	0.000	0.000	0.031	0.000	350	305	125	780	860
7/04	0.560	0.440	0.000	0.000	0.000	0.000	290	300	165	755	925
8/04	0.571	0.415	0.000	0.000	0.014	0.000	340	350	205	895	1985
9/04	0.477	0.490	0.000	0.000	0.033	0.000	350	395	190	935	1125
10/04	0.442	0.537	0.000	0.000	0.021	0.000	420	500	205	1125	1235
11/04	0.317	0.674	0.000	0.000	0.010	0.000	505	610	255	1370	1390
12/04	0.247	0.741	0.000	0.000	0.012	0.000	450	485	140	1075	865
1/05	0.429	0.548	0.000	0.000	0.023	0.000	620	625	175	1420	1360
2/05	0.160	0.830	0.000	0.000	0.010	0.000	515	545	160	1220	500
3/05	0.176	0.774	0.000	0.000	0.050	0.000	575	490	145	1210	330
4/05	0.180	0.788	0.000	0.000	0.033	0.000	570	615	210	1395	345
5/05	0.098	0.878	0.008	0.000	0.015	0.000	610	680	210	1500	600
6/05	0.069	0.873	0.029	0.000	0.029	0.000	550	615	190	1355	685
7/05	0.060	0.878	0.017	0.000	0.044	0.000	540	815	205	1560	780
8/05	0.050	0.849	0.006	0.000	0.095	0.000	595	850	210	1655	905
9/05	0.060	0.838	0.021	0.000	0.081	0.000	565	900	225	1690	790
10/05	0.019	0.755	0.044	0.000	0.181	0.000	785	990	245	2020	1000
11/05	0.014	0.736	0.025	0.000	0.222	0.004	790	730	140	1660	380
12/05	0.029	0.616	0.012	0.000	0.344	0.000	830	830	155	1815	665
1/06	0.025	0.635	0.017	0.147	0.141	0.035	780	645	140	1565	615
2/06	0.006	0.600	0.006	0.156	0.133	0.098	910	735	140	1785	595
3/06	0.021	0.573	0.006	0.154	0.156	0.089	1135	780	160	2075	805
4/06	0.019	0.488	0.037	0.085	0.224	0.147	1130	860	190	2180	1060
5/06	0.015	0.467	0.029	0.091	0.224	0.174	1215	1055	230	2500	1100
6/06	0.017	0.442	0.037	0.104	0.309	0.091	1155	1045	260	2460	1120
7/06	0.025	0.280	0.033	0.191	0.346	0.125	1230	1165	245	2640	1680
8/06	0.017	0.328	0.017	0.284	0.286	0.068	1275	1215	215	2705	1455
9/06	0.015	0.311	0.019	0.326	0.255	0.073	1365	1275	265	2905	2015
10/06	0.021	0.297	0.012	0.309	0.292	0.069	1375	1505	275	3155	2225
11/06	0.039	0.241	0.008	0.363	0.299	0.050	1395	1185	220	2800	1900
12/06	0.025	0.164	0.019	0.382	0.342	0.068	1305	1280	255	2840	2120
1/07	0.025	0.139	0.012	0.477	0.284	0.064	1235	1165	225	2625	2435
2/07	0.054	0.151	0.008	0.450	0.263	0.075	1465	1050	190	2705	1775
3/07	0.066	0.120	0.012	0.461	0.286	0.056	1645	1205	205	3055	1745
4/07	0.068	0.124	0.029	0.486	0.222	0.071	1415	1265	225	2905	1915

LPRC/HPRC: Low Power/High Power Radio Control

PI: Passive Infrared

CW: Command Wire

PP: Pressure Plate

CP: Cell Phone

IED-FC: IEDs Found/Cleared

IED-I: Ineffective IEDs

IED-E: Effective IEDs

IED: Total IED Attacks

NIED: Total Non-IED Attacks